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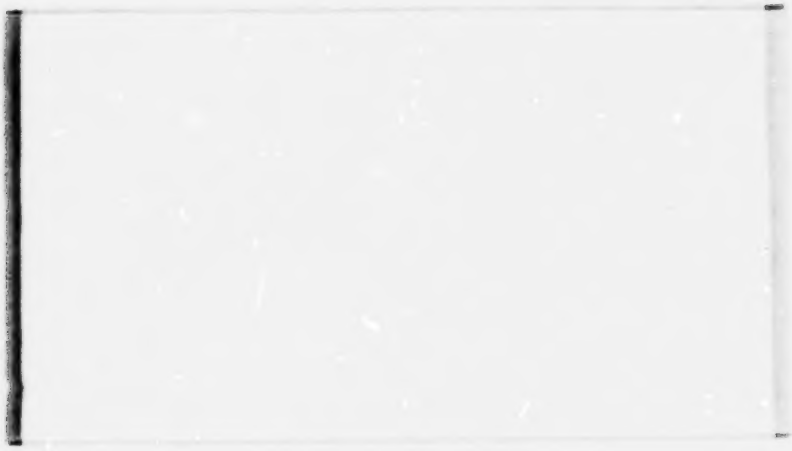

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ROBOTIC INSPECTION OF PROTOTYPE TITANIUM DIFFUSION BOND FINAL CLOSURE WELD – INTERIM DEMONSTRATION

Report 87-26-K

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Metallurgical Research Department

ABSTRACT

This report describes the initial phase in performing a robotic inspection demonstration on a prototype titanium diffusion bond nuclear used fuel container final closure weld. The inspection technique and configuration are briefly described. The two-stage inspection process (mapping and scanning) is described in more detail, along with the user interface and robot control. The limited results show a satisfactory correlation, though differences in scan patterns limit the comparison. The main problems with this technique are the unknown system accuracy and the slow inspection speed.

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EXECUTIVE SUMMARY

ROBOTIC INSPECTION OF PROTOTYPE TITANIUM DIFFUSION BOND FINAL CLOSURE WELD - INTERIM DEMONSTRATION

D.J. Dowker and M.D.C. Moles
Nondestructive and Fracture Evaluation Section
Metallurgical Research Department

This report describes an interim demonstration of the ultrasonic inspection of a prototype titanium diffusion bond final closure weld for a nuclear used fuel container using a PUMA 560 robot. The ultrasonic inspection technique, developed previously, is briefly described. The inspection system consists of the robot controlled by an IBM-PC compatible computer, an ultrasonic flaw detector, transducer, waterjet and waterbath for coupling. Inspections are performed in a two-stage process, mapping and C-scanning. Mapping involves measuring the location and orientation of the surface. C-scans are area-amplitude plots of the diffusion bond at a pre-determined depth range to show any reflectors. Mapping is performed by maximizing the ultrasonic signal on the frontwall to determine the "normal" orientation, and then moving the signal out of the flaw detector's gate to determine correct water path distance. C-scans are performed by moving vertically down the cylinder from the mapped line of points. The limited results show a satisfactory correlation with previous scans, though scan sizes and ultrasonic parameters varied significantly. This interim demonstration showed two main limitations: speed and accuracy. The two step process proved to be very slow, but could be speeded up either by interpolation or with a better tracking sensor. Accuracy is not quantified yet, but should be examined in the next phase. Overall, the demonstration indicates that this type of procedure could be used for in-service inspections of final closure welds.

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ROBOTIC INSPECTION OF PROTOTYPE TITANIUM DIFFUSION BOND FINAL CLOSURE WELD – INTERIM DEMONSTRATION

1.0 INTRODUCTION

1.1 Nuclear Fuel Waste Disposal Program

The current Canadian concept for disposal of used fuel from CANDU nuclear reactors is to isolate the fuel in corrosion-resistant containers and to place the containers at a depth of 500 to 1000 m in plutonic rock. As a part of its Technical Assistance Program within the Nuclear Fuel Waste Management Program of Atomic Energy of Canada Limited, Ontario Hydro is performing containment and immobilization studies. Part of this program involves developing remote nondestructive evaluation (NDE) techniques for the final closure weld of the used-fuel immobilization container. Ultrasonic inspection (UT), which can be performed remotely, is potentially the most useful NDE technique for weld inspection, possibly supplemented by other techniques. The objective of the NDE inspection is to ensure the mechanical integrity of the weld, and that a necessary minimum corrosion barrier exists/1-3/.

1.2 Titanium Diffusion Bonds

One of the candidate concepts for a waste disposal container involves a thin-walled, corrosion-resistant container made of 4.76 mm thick titanium plate (Figure 1)/4/. Conventional fusion welding of titanium alloys presents problems due to weld contamination, and diffusion bonding has been investigated as a potential alternative. Diffusion bonding consists of pressing two sheets of metal together under conditions of time, temperature and pressure sufficient for diffusion to occur and give a metallurgical bond. Melting does not occur. The pressure, temperature and time conditions, and freedom from contamination at the interface, are important in producing a sound joint with no lack of bonding.

This report describes the intermediate development stage of a program to ultrasonically inspect a prototype titanium diffusion bond ring using a PUMA 560 robot. The objective is to demonstrate that diffusion bonds can be reliably inspected remotely. The system, as it currently exists, is examined and its performance assessed with attention given to areas which need further development.

2.0 ULTRASONIC INSPECTION TECHNIQUE

From previous work it was found that the use of normal beam fusion line pulse echo ultrasonic inspections produced the most satisfactory results on titanium diffusion bonds/3,5/. In this technique the normal beam transducer receives a signal from the region between the upper and lower plates if there is a lack of bonding. As seen in Figure 2, the normal beam transducer has to be coupled to the surface through a medium which does not restrict its high frequency sound waves. In the past the transducer and diffusion bond were immersed in water. In the robotic inspection system, a waterjet is used for coupling which may be a simpler procedure to use in a remote fabrication and inspection facility, rather than full immersion of the used-fuel containers.

Due to the surface ridges created by the bonding process, the waterjet-coupled transducer is favored over a contact transducer. The use of a contact transducer is further inhibited by the fact that they too must be coupled to the surface but with a substance which does not adapt easily to remote handling techniques. Contact coupling has proven to be of variable quality.

The end product of the inspection process is an area amplitude contour scan, called a C-scan, of the bond line region in the segment of the ring inspected. The C-scan (Figure 3) provides a graphical representation of the interface between the upper and lower plates with different colours corresponding to the varying reflected signal amplitudes. The vertical and horizontal distances represented by the C-scan are adjustable to provide controllable levels of resolution.

Without the use of a contact transducer, the accuracy of the inspection system's surface tracking must be greatly increased since reflected signal amplitudes decline rapidly with misorientation. The bond line must also be held at a constant distance from the transducer. If this distance changes by less than one millimeter, the reflected signals from the front or back wall of the surface can drift into the ultrasonic flaw detector's gate and be mistakenly interpreted as a bond defect. The inspection system's main concern is therefore the accurate tracking of the bond ring, thereby producing valid final results.

3.0 INSPECTION SYSTEM CONFIGURATION

The center of the inspection system is an IBM-PC compatible Sperry model 50 personal computer. It acts as the user interface to the system, carries out the data collection and controls the tracking of the surface through the flaw detector and robot controller. As seen in Figure 4, the microcomputer's RS-232 serial port is connected to the PUMA 560 robot controller's terminal port to provide their communication path. The EPOCH 2002 ultrasonic flaw detector provides a 0 to 1 volt analog output which is proportional to the signal in its gate. This signal is interfaced to the Sperry through a Labtender -5 to +5 volt a/d board.

The EPOCH flaw detector pulses and receives its signal from a waterjet-based Harisonic 15 MHz flat ultrasonic transducer. The waterjet itself is attached to the robot's tool mounting flange by an aluminum plate (Figure 5). An immersion pump provides the waterjet with the water, which strikes the surface of the diffusion bond and is recycled. The power supplied to the pump is controlled by a variable transformer so that the water pressure and flow may be adjusted.

Tracking of the bond ring is accomplished with the PUMA 560 robot and its associated PDP-11 controller (Figure 6). The robot controller provides its own interpreter-based programming environment named VAL II. VAL II is an operating system and programming language. The operating system controls the environment and works from individual "monitor" commands. It includes a line editor for program creation and a means to read and write to and from its floppy disk drive. The operating system is, for the most part, always accessible from the system terminal even during program execution. This allows monitor commands to be issued while a program is running and a program that is running can be edited, thereby affecting its execution. Both the operating system and the programs are able to drive the robot arm. In addition, the PUMA 560 comes with a teach pendant which allows direct movement of the robot arm and elementary programming.

VAL II provides a structured programming environment where all resident programs and variables are considered global in scope. The controller places resident programs, numeric variables and location variables in three separate pools of memory making them accessible for later use. Programs, numeric variables and location variables can be stored and read to and from disk separately or in mixed groups to be added to these pools of active data. Variables are automatically created, if they do not exist, when referenced by a monitor or program instruction. Explicitly removing programs and data through monitor commands is the only way to clear them from memory without having to initialize the whole system. To maintain the operating environment between sessions, the controller utilizes a 30-day battery-backed-up CMOS memory.

In the robotic inspection system, the Sperry RS-232 serial port initiates execution of specific VAL II programs via the robot controller's terminal port. It also maintains synchronization with these routines, when needed, by waiting and responding to specific prompts from the VAL II routines.

4.0 INSPECTION PROCESS

The present system requires two separate steps to produce a C-scan. The first step maps out the locations on a horizontal line of points in which the transducer is perpendicular to, and at the correct distance from the surface. These locations are stored in the robot controller. The second step successively uses each of these mapped points to C-scan a vertical segment of the surface (Figure 7). For this intermediate stage of program development, it is assumed that the surface is aligned with the robot Z-axis so that a constant water path will be maintained during the vertical scan. A column of C-scan data is collected at each mapped point. The C-scan is complete when there are no more mapped points to be scanned or a preset horizontal stopping distance has been reached.

4.1 Mapping of the Surface

The process of mapping a point requires the use of all components of the system. The signal in the flaw detector's gate provides the positional information that is used. As seen in Figure 8, the gate covers an area sufficiently large enough to contain the front wall reflection from the surface. This reflection is by far the most dominant in amplitude, thereby dictating the flaw detector's analog output. The start of the gate corresponds to the ideal distance of the transducer to the

front wall. To produce a mapped point, the transducer is first aligned perpendicular to the surface and then is placed the correct distance from it.

4.1.1 Placing the Transducer Normal to the Bond

To initiate the location of the normal orientation, the Sperry calls the Puma 560 to execute a routine which slowly pivots the robot's wrist horizontally (Figure 9). At the same time, the Sperry monitors the analog input to keep a record of the maximum reading taken. When there is no longer a signal in the gate the Sperry directs the robot controller to reverse direction on the wrist movement. The maximum signal is again recorded. When the gate again loses its signal the microcomputer tells the robot to reverse the direction of rotation. On this pass, it waits until a threshold quite close to the maximum is reached and then signals the robot to stop motion.

It is necessary to make the two complete passes over the front wall signal to find the maximum threshold since the placement of the normal relative to the current position is not originally known. By using two passes, at least one will have crossed over the normal.

This method proved quite successful in finding the point of maximum front wall signal amplitude when the wrist rotation speed was kept below a certain limit. The limiting speed is dependent on the analog update rate from the flaw detector and the ability of the system to stop the robot motion with sufficiently small delay.

The method used assumes that the transducer and surface are always aligned in the vertical plane. Essentially this requires the base of the robot and the base of the diffusion bond ring to be on parallel planes. When finding the horizontal point of maximum amplitude by the means described, only the wrist motor is driven, providing a smooth motion. Otherwise, this would require the pivot point to be accurately defined and the robot would be using joint-interpolated motion of its six joints to carry out the motion. These combined inaccuracies would compromise the final results.

A further complication to this normalizing process is the fact that the vertical face of the surface above and below the bonded region may not be flat due to deformation of these areas during the diffusion bonding process. This introduces the question of where is the best place to map out the surface. The bonded region has a rough face which would affect the quality of the reflected signal, but has the vertical plane orientation desired. The faces above and below the bond may be on a slight angle, but have smooth surfaces that produce more uniform reflected signals. Therefore, the assumption that the surface was aligned to the robot's Z-axis was made and any small variations were tolerated.

Another method that was tried to find the normal was to follow the increasing signal, then, when the signal started to decrease, reverse the direction of the wrist motion and lower the speed of travel. This would be repeated until a position sufficiently close to the normal, was established. This method provided faster results, but too often tracking was lost due to random fluctuations in the signal. These fluctuations could not be suppressed with signal averaging or slower rotation speeds. Further investigation will be needed to determine if the amplitude fluctuations were caused by the reflected signal or the slow updating of the analog output.

4.1.2 Maintaining the Correct Distance to the Bond

Once the transducer is pointing along the normal it must be placed the correct distance from the surface. This operation does not require the gate on the flaw detector to be altered. The Sperry calls upon the robot controller to move along the normal towards the surface while it monitors the gate signal. When the signal drops by at least fifty per cent of its value, the motion stops. This places the front wall just before the gate (Figure 10). This operation proved to be quite successful in maintaining the front wall at a constant distance from the surface. The speed with which this operation could be carried out was limited by the response time required to stop the motion and the update rate of the flaw detector's analog output.

4.1.3 Completing a Mapping

When the robot is placed correctly, the position is recorded by the robot controller. The transducer is then moved away from the surface along the normal line until the front wall is back in the gate. The arm's tool point is then shifted horizontally by a small distance, previously specified by the user, and the next point is mapped. This process continues until a pre-specified mapped surface distance has been covered or the robot has mapped 360 degrees, depending on user-set parameters.

4.2 Creating C-Scans

Once an area of the of the ring has been mapped, C-scans can be produced of different segments of this area. The flaw detector's gate must now be reduced in width to only cover the region between the upper and lower plates (Figure 11). This need only be done once since the distance from the transducer to the surface is held constant along the mapping. The user interface allows the robot to be moved to any of the mapped points to start a C-scan. A C-scan can be carried out for a pre-specified distance or for the entire mapping.

To begin a C-scan, the Sperry calls upon the controller to move to the closest mapped point. The controller then moves a preset distance in the vertical direction holding the orientation of the mapped point. During this time the Sperry samples the gate signal to produce one column of the C-scan on the microcomputer display. The controller then moves to the next point and the actions are repeated. The C-scans are displayed on the Sperry's color graphics monitor and are written to disk on completion of a scan or when the Sperry's screen has been filled.

4.3 User Interface

The user interface for the inspection system is a menu-driven system of windows and data entry panels (Figure 12). It was designed using the Panel Screen Design Aid utility program which transformed the designed screens into C language data structures. PANEL provided a library of routines for full control of data input and screen manipulation.

With the interface, the user can set up the specifications for a mapping or C-scan and then carry out the process. The menus also allow direct keyboard control of movement along the mapped surface and the displaying of previous C-scans that

were stored to disk. While processes are under way the system displays pop-up messages to inform of any user action required.

Due to the saving of the Puma 560's environment by its battery-backed-up memory, the Sperry environment is also saved and read back from disk between sessions. This allows a user to start up from the last scan if the bond ring surface has been left undisturbed.

4.4 Robot Control

As mentioned previously, the Sperry initiates the execution of routines in the robot controller via the terminal port. VAL II routines were written for each movement that the robot arm would be expected to perform. Macro routines were then created that combined these small tasks into complete operations such as mapping, moving along the mapped surface, and scanning.These macro routines are closely locked in synchronization with the Sperry routines to carry out the desired functions.

The primary use of synchronization between the coroutines is to initiate the start of a new phase of a macroroutine. In the case of mapping the surface, the Sperry must tell the robot when to start finding the normal and then when to start to move the correct distance. It then must resynchronize, when the robot has shifted to the next point, to begin the process again or be informed that the robot has completed the mapping according to the specifications passed to it. Synchronization is accomplished by the Sperry waiting for a specific prompt, issued out the terminal port by the controller, and then responding to it by issuing a carriage return. VAL II has a specific command to output a message and then wait for keyboard input which satisfies the macroroutine's synchronization needs. If the Puma 560 is waiting for the Sperry, its prompt will be contained in the Sperry's RS232 controller so it will not be missed.

There is a second type of synchronization that is implemented by the system. VAL II provides software flags that can be accessed by both the operating system and routines. These are used to provide signals between the Sperry and the macroroutines when the robot motion cannot be stopped to wait for keyboard input. This occurs to modify the motion according to the signal received any time the robot is moving while the Sperry is monitoring the flaw detector output. This is used when finding the normal and moving in to the correct distance.

In addition to synchronization, there is a need to pass information from the Sperry to the controlier. The parameters for a mapping or a C-scan are passed prior to the macroroutine being executed so that only synchronization need be carried out between the two routines while a process is underway. Data can be passed to the Puma using monitor commands to update variables via the operating system.

This method of synchronization proved to be reliable in the passing of information between the two computers.

5.0 RESULTS

To judge the accuracy of the inspection system, C-scans were taken of an area where deliberately implanted defects existed. The C-scans produced were compared

with C-scans performed previously in the laboratory, using conventional immersion ultrasonics/6/. Delivery system accuracy is considered to be of primary importance.

As can be seen in Figure 13, the inspection system provides C-scans which correspond quite closely to those obtained using immersion ultrasonics. Both are able to detect deliberately implanted defects between the plates and lack of bonding. With the robotic system, the collection of invalid data due to front wall drift occurred rarely. When it did occur, it affected only a few consecutive points in the C-scan. Unfortunately, the scans are different in scale and ultrasonic parameters, so direct comparisons are difficult. It will be necessary to obtain immersion C-scans of higher resolution and more similar parameters to truly determine the degree of correlation, but at this stage, these results are encouraging.

6.0 DISCUSSION

6.1 System Accuracy

Despite these encouraging results, further investigation is needed in many areas that may affect system performance. One area of concern is roughness on the outer surface. Finding the correct orientation for maximum front wall signal intensity along one horizontal strip may not guarantee accurate C-scans of the bond line. In addition, alternative methods should be attempted for mapping the surface to remove the effects of surface irregularities. At present, only one mapped point controls the orientation of an entire C-scan column, which may not be representative of the surface along this vertical strip. The mapping of multiple points along the vertical could be investigated to see if there is any significant increase in the accuracy obtained to justify the extra time needed for this procedure.

Methods of accurately finding the normal at a point using both the horizontal and vertical planes should be investigated to see if the results obtained are beneficial to the C-scans produced. This line of investigation should be pursued with a view to expanding the current system to handle three dimensional components whose shapes vary in all planes.

The motion of the robot arm also accounts for a certain amount of system inaccuracy. The required time to reach the set motion speed requested and the subsequent deceleration period caused too many samples to be taken at the top of a scan and the sampling was complete before the set scan distance was reached. The small initial distortion is reduced if the speed of the scan is also reduced. This problem can be further resolved by placing the top of the scan area in the non-bonded region and scanning over a longer distance. A potential problem, which cannot be so easily verified or resolved, is the path that the arm takes when travelling along the vertical line. The robot controller sends update information to its servomotors every 28 ms but the actual accuracy of the straight line path is not known. Slower speeds may improve this accuracy.

Part of the inaccuracy of the present system can be attributed to the means of supporting the bond ring. The stand used does not provide the stability that is desired and the use of a waterjet may cause a certain amount of swaying of the test piece to occur. Further investigation into the mapping and scanning process will be needed if accuracy is to be improved.

6.2 System Speed

Secondary to accuracy, but important to a user, is the time needed to produce a C-scan. The present system takes approximately 7.5 seconds to map a single C-scan column and, since the Sperry screen contains 320 columns, it requires approximately forty minutes to map enough points to create one full-screen C-scan. Combined with the time to carry out the C-scan, this results in a very slow system. Although the speed of the system is generally not important in this feasibility study, a more efficient approach should be sought.

The time needed to map a point is mainly a function of the accuracy required in the placement. Higher accuracy requires the use of slower robot motion speeds. The analog update rate of the flaw detector used and the quality of the signal values received by the Sperry also affect the method and speeds chosen to map the point accurately. With the present equipment, the mapping and scanning times cannot be significantly improved. The use of a flaw detector with a faster update rate and a JR3 surface tracking sensor should be investigated to determine if their use is justified.

6.3 Alternatives to the Two-Step Process

Significant improvements in the time needed to carry out a C-scan with the present system will only be found by improving the overall process. At present, a new mapping is needed each time the horizontal resolution of the scan is changed or an unmapped area needs to be scanned.

If the mapping process could be carried out once and intermediate points interpolated for different horizontal spacings, then the system speed would be increased. The problem with interpolation is that variations from the true values must be minuscule for the accuracy required in such an ultrasonic inspection system. The front wall reflection must be maintained at a constant distance from the surface or it may end up within the gate. Straight-line interpolation was attempted between points but proved unsuccessful. It may be worthwhile to explore more involved interpolation techniques to remove the need to map the surface more than once.

6.4 Software

The inspection system is written in the C programming language and uses the Panel Screen Design Aid with the objective of making the code both maintainable and expandable. The code checks for many errors that may occur during the course of its processes but more error checking and recovery need to be developed. At present, there is no recovery from a loss of synchronization between the two computers that may be caused by the robot aborting its macroroutine through some hardware or software condition. This requires the Sperry to be reinitialized and the current parameter settings cannot be saved to disk. The use of timeouts (preset time periods, after which if no communication occurs between the robot and computer, the program is aborted) during synchronization periods should be implemented.

The present inspection system operates without knowledge of the shape of the object it is inspecting. This means that the system can be used to inspect other objects that have a flat vertical plane, such as a plate or block. While this provides added flexibility, it also prevents the actual dimensions of a displayed C-scan from

being displayed. To be able to compute the size of the bond ring path displayed in the scan, the path traced along the surface by the normal beam would have to be calculated according to the object's shape and the distance the robot tool's origin is away from it. Currently the horizontal distance can only be estimated by the step size used during the mapping process.

The flexibility of the inspection system to incorporate different equipment should also be increased. Although one of the input panels allows the specification of the type of display and analog-to-digital (A/D) boards used, these choices have not yet been implemented. If the accuracy of the system can be improved, then it would be beneficial to use the Sperry's 320X400 256 colour mode. This would provide more detailed contour scans than those currently produced with the standard colour graphics mode.

On the whole, the preliminary implementation of the system has achieved its objective of inspecting the diffusion-bonded ring. This procedure could be used for the actual in-service inspection of final closure welds using radiation-resistant components, though there are the limitations described. Further enhancements discussed will produce a system which is more flexible and reliable.

7.0 CONCLUSIONS

1. *Initial results indicate that the robotic inspection system is able to inspect a prototype titanium diffusion bond, and these correlate well with previous inspections.*

2. *The current method of tracking the surface using the signal from the waterjet-based transducer has proven to be extremely slow.*

3. *The present mapping system is limited by the ability of the transducer to maintain a constant distance to the surface and the accuracy to which the distance between the surface and transducer can be held constant.*

4. *Overall, the demonstration indicates that this type of procedure could be used for in-service inspections of nuclear used-fuel container final closure welds.*

8.0 RECOMMENDATIONS

1. *C-scans of the diffusion bond with higher resolution should be made using conventional immersion ultrasonics to determine the actual accuracy of the inspection system.*

2. *The assumption that the vertical planes of the surface and the robot are aligned should be discarded and the system expanded to handle three-dimensional tracking. The use of the JR3 surface tracking sensor and a flaw detector with improved update rate should be investigated.*

3. *Accurate interpolation techniques should be investigated so that the surface need be mapped only once.*

4. System software should be developed to recover from errors in the synchronization between the Sperry microcomputer and the robot controller.

9.0 ACKNOWLEDGEMENTS

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DJD/MDCM:SEH

REFERENCES

1. D.J. Cameron, J.L. Crosthwaite and K. Nuttall, "The Development of Durable, Man-Made Containment Systems for Fuel Isolation", Canadian Metallurgical Quarterly, Vol. 22, No. 1, p. 87, 1983.

2. K. Nuttall, J.L. Crosthwaite, P. McKay, P.M. Mathew, B. Teper, P.Y.Y. Maak and M.D.C. Moles, "The Canadian Container Development Program for Fuel Isolation", Materials Research Society Sixth International Symposium on the Scientific Basis for Nuclear Waste Management, Boston, MA, November 1–4, 1982.

3. M.D.C. Moles and A.L. Allen, "Ultrasonic Inspection of Titanium Diffusion Bonds for Nuclear Used Fuel Containers", 11th World Conference on NDT, Las Vegas, NV, November 3–8, 1985, Vol 3, P. 1502.

4. B. Teper, "Evaluation of the Design of Particulate-Packed, Thin-Wall Container for Disposal of Irradiated Fuel Bundles", Proceedings of CNS International Conference on Radioactive Waste Management, Winnipeg, Manitoba, September 12–15, 1982.

5. M.D.C. Moles and A.L. Allen, "Ultrasonic Inspection of Titanium Diffusion Bonds for Nuclear Fuel Waste Containers", AECL Report No. TR-241, September, 1984.

6. R. Ginzel, unpublished Ontario Hydro Research Division work.

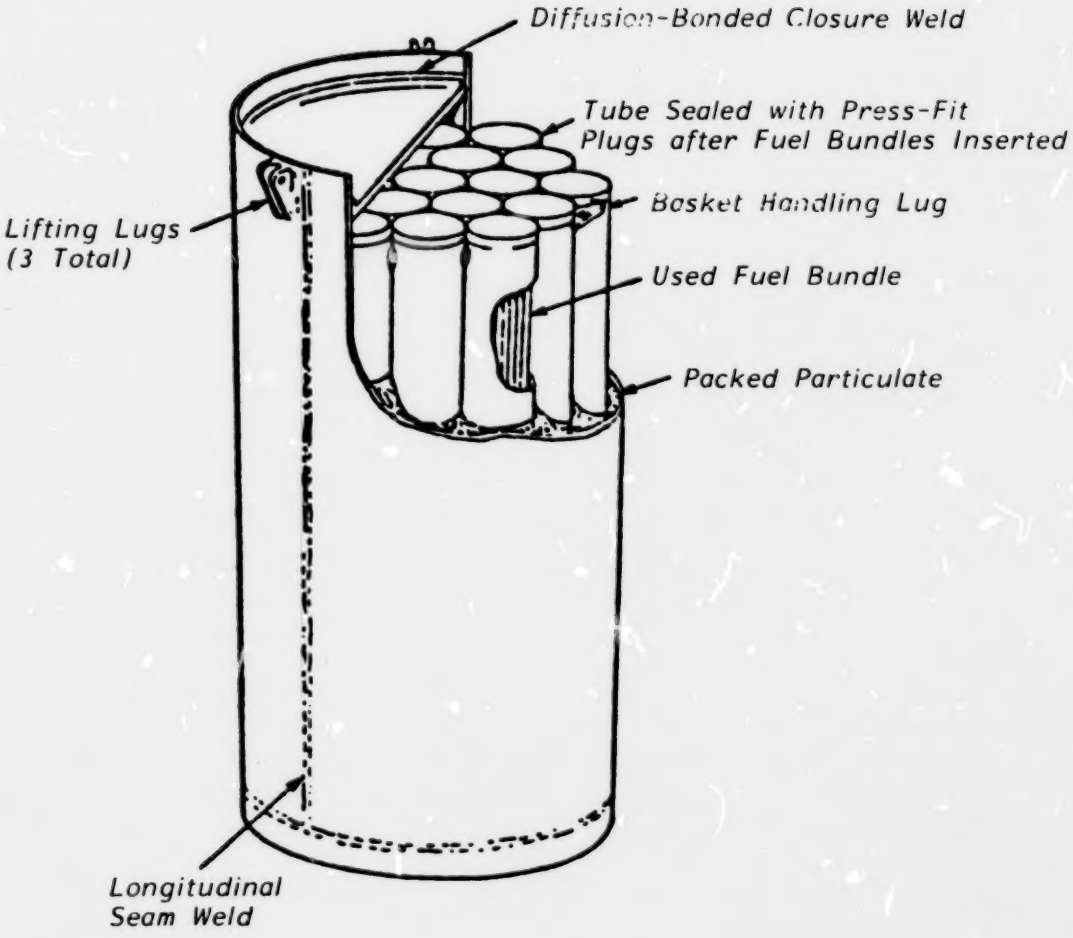

FIGURE 1

A CANDIDATE NUCLEAR FUEL WASTE DISPOSAL CONTAINER

173863-RD

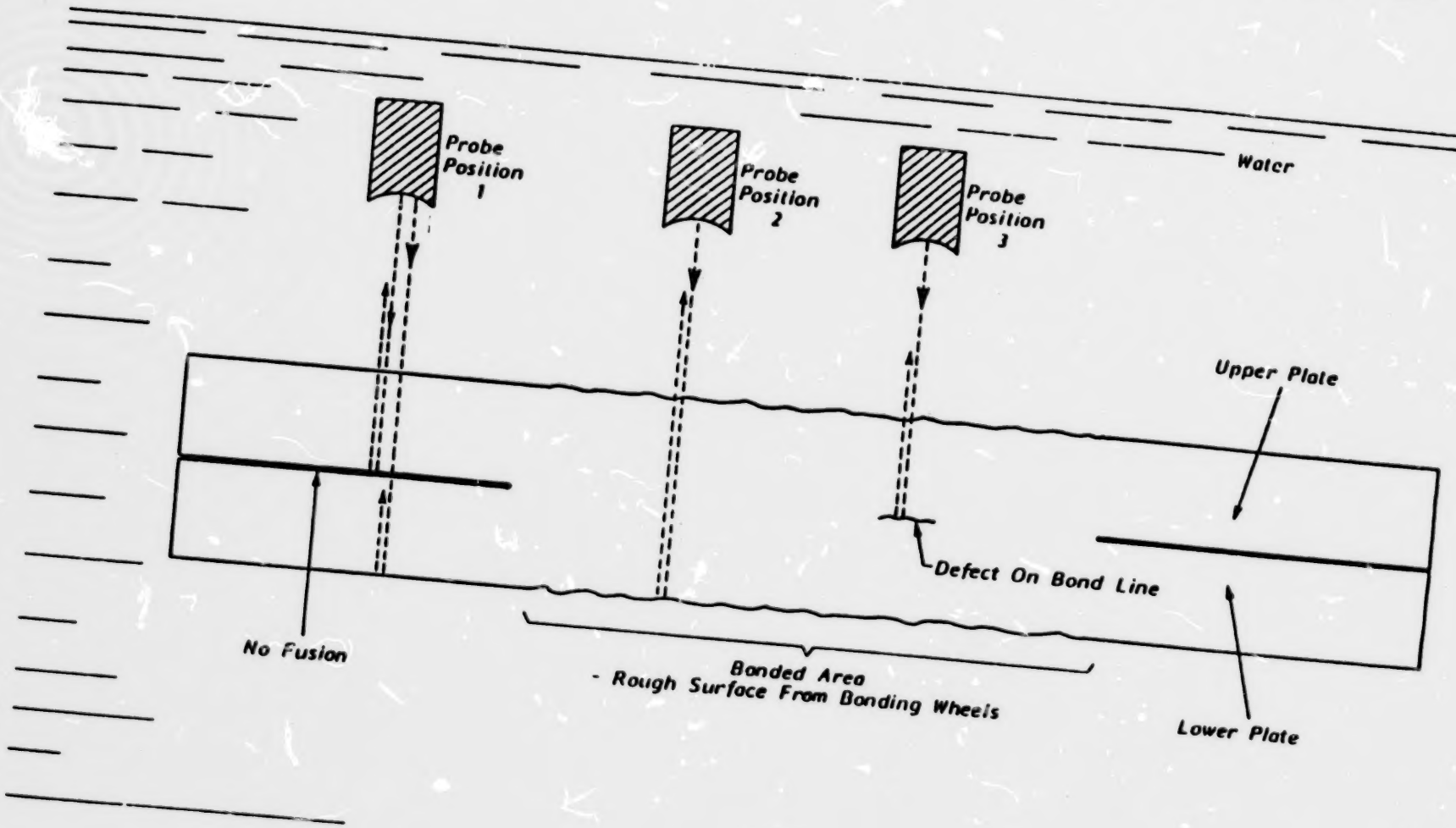

FIGURE 2

IMMERSION NORMAL BEAM FLPE INSPECTION OF DIFFUSION-BONDED PLATES

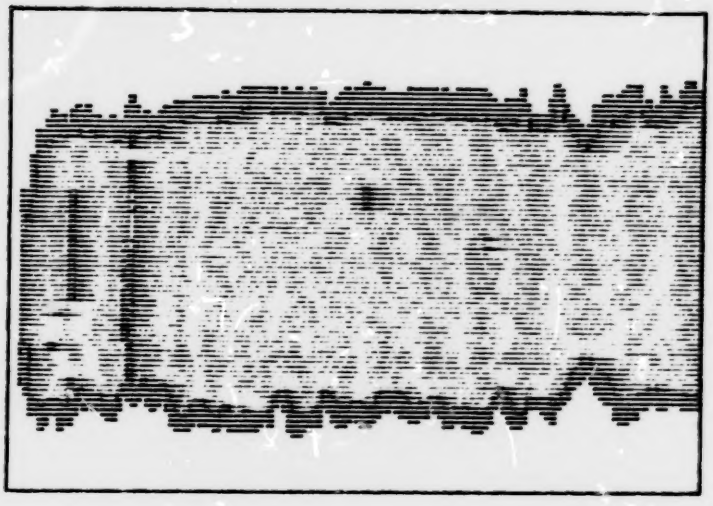

FIGURE 3
AN EXAMPLE OF A C-SCAN USING IMMERSION ULTRASONICS

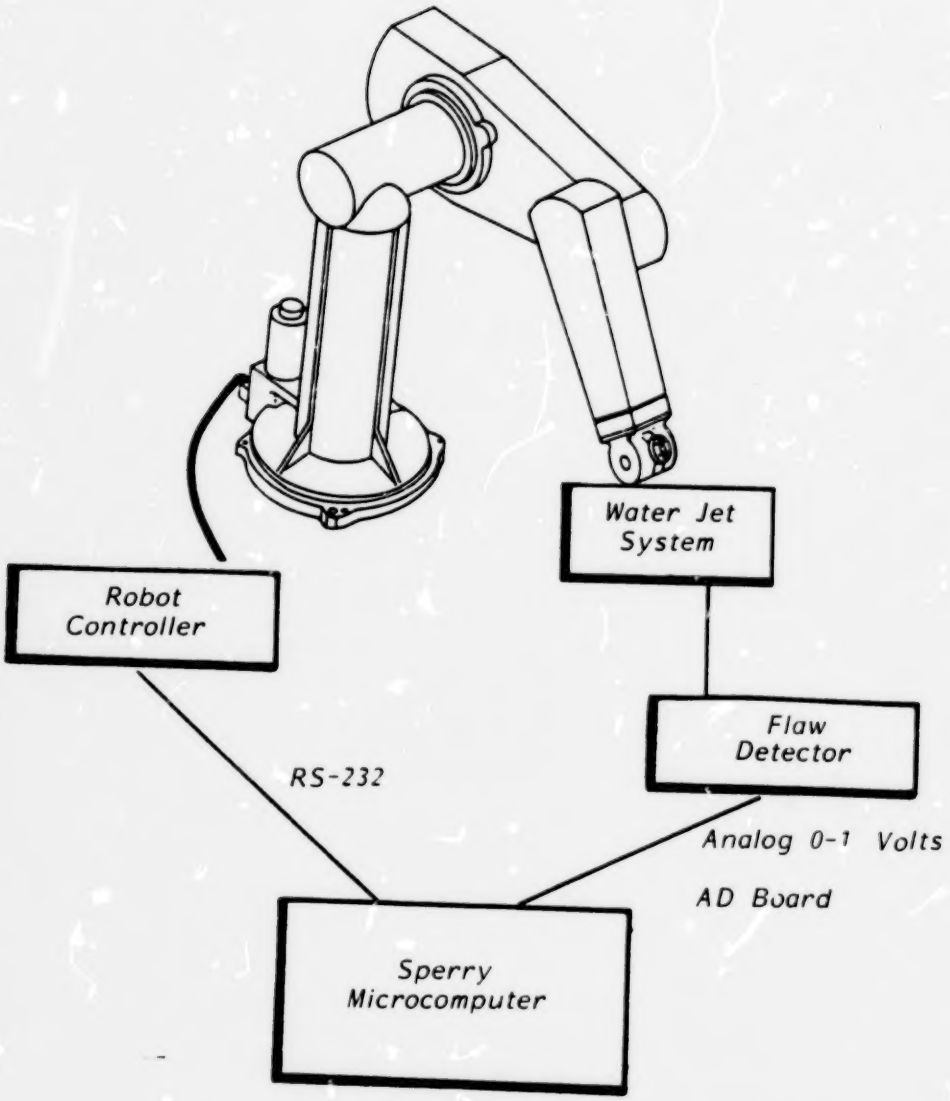

FIGURE 4
INSPECTION SYSTEM CONFIGURATION

173866-RD

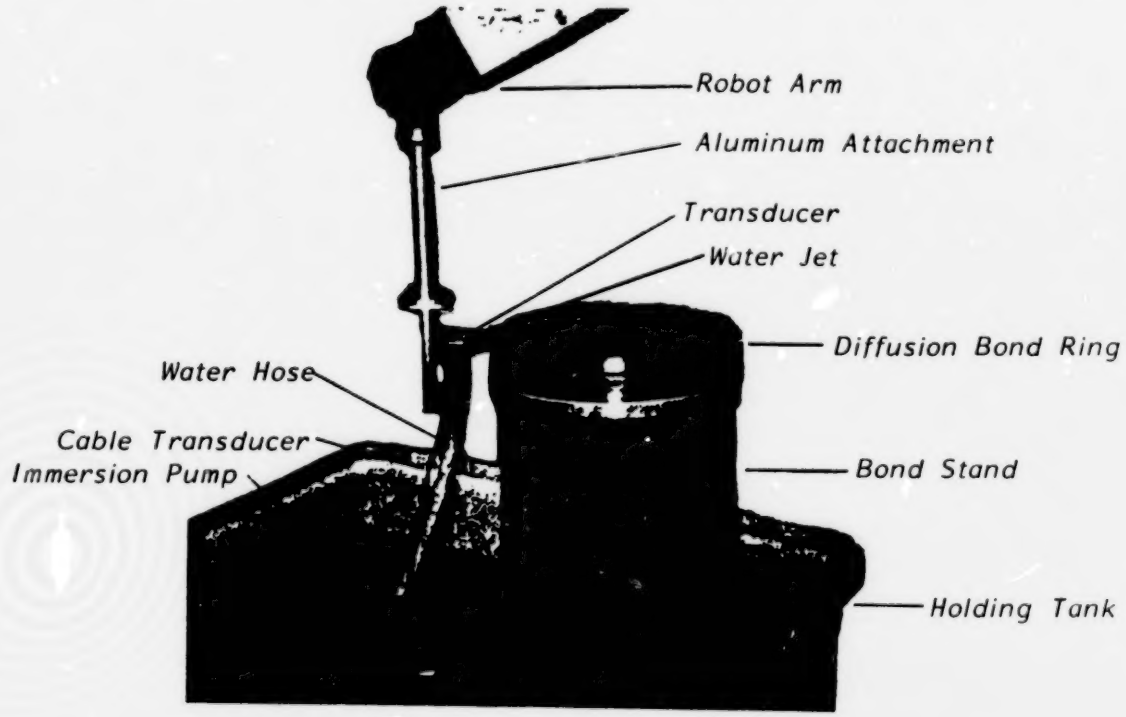

FIGURE 5
WATER JET SUBSYSTEM

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FIGURE 6
PUMA MARK 11, 500 SERIES, ROBOT SYSTEM

173868-RD

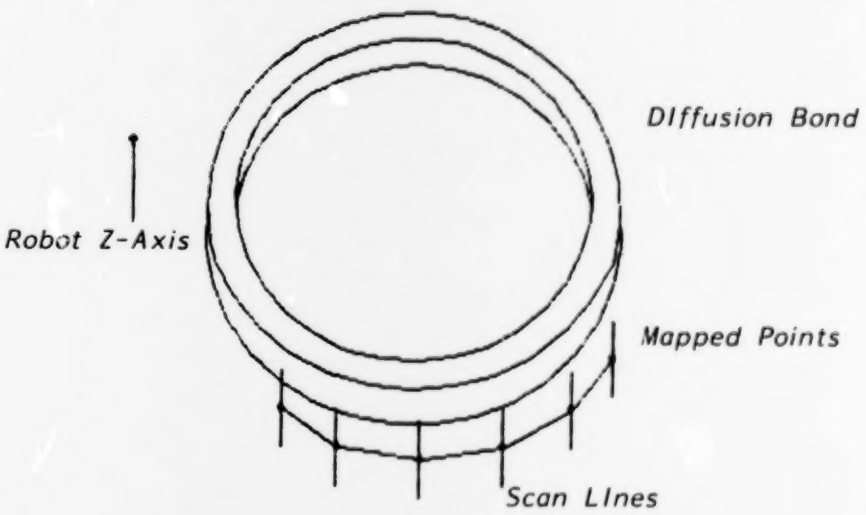

FIGURE 7
TWO-STEP PROCESS TO PRODUCE A C-SCAN

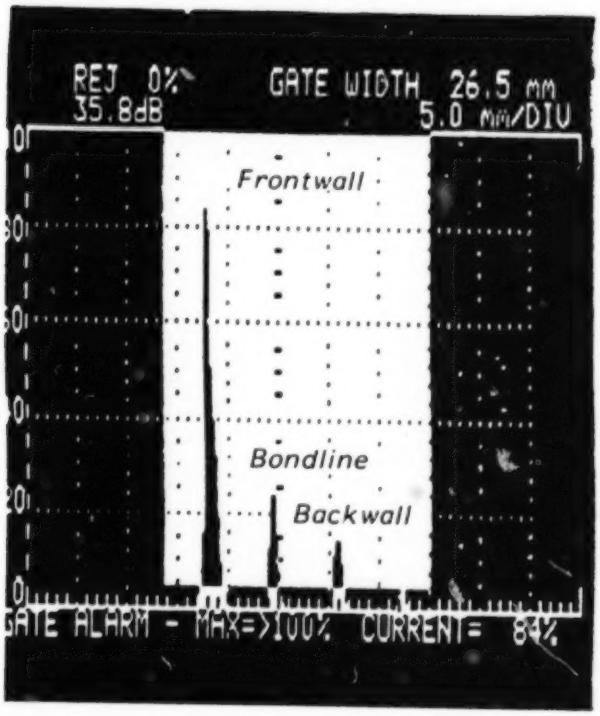

FIGURE 8
PROPER SETUP OF FLAW DETECTOR'S GATE FOR MAPPING

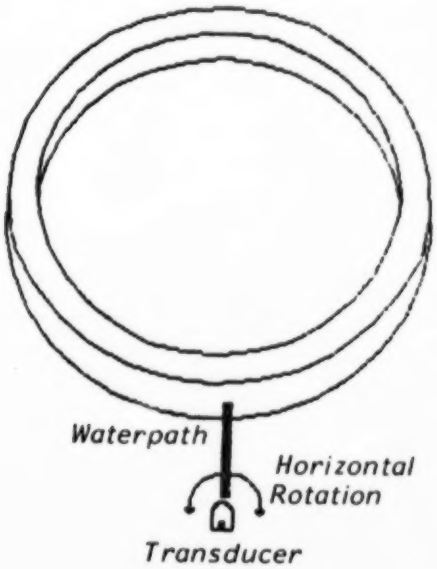

FIGURE 9
METHOD OF FINDING THE NORMAL

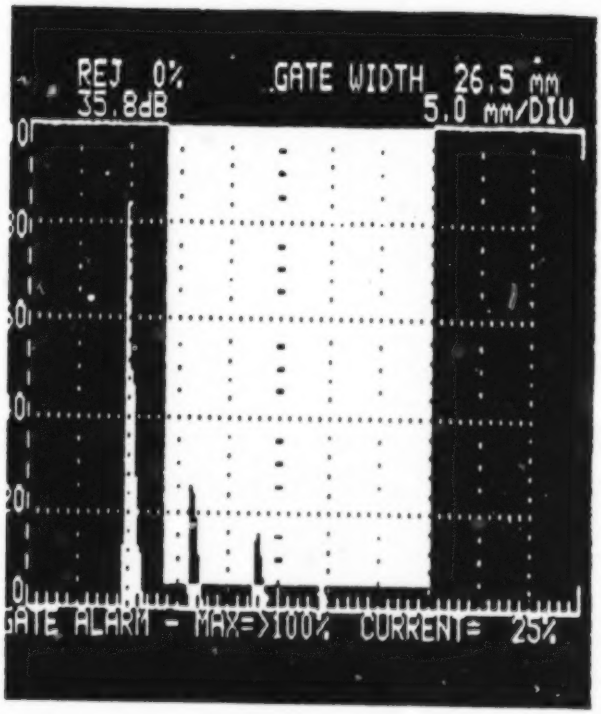

FIGURE 10

POSITION OF FRONT WALL WHEN
CORRECT DISTANCE TO SURFACE IS FOUND

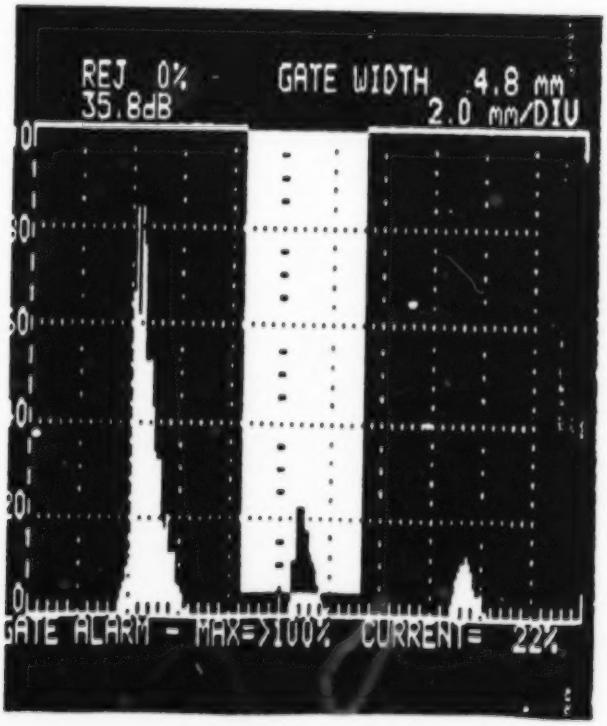

FIGURE 11

PROPER SETUP OF THE FLAW DETECTOR'S GATE
WHEN CREATING C-SCAN

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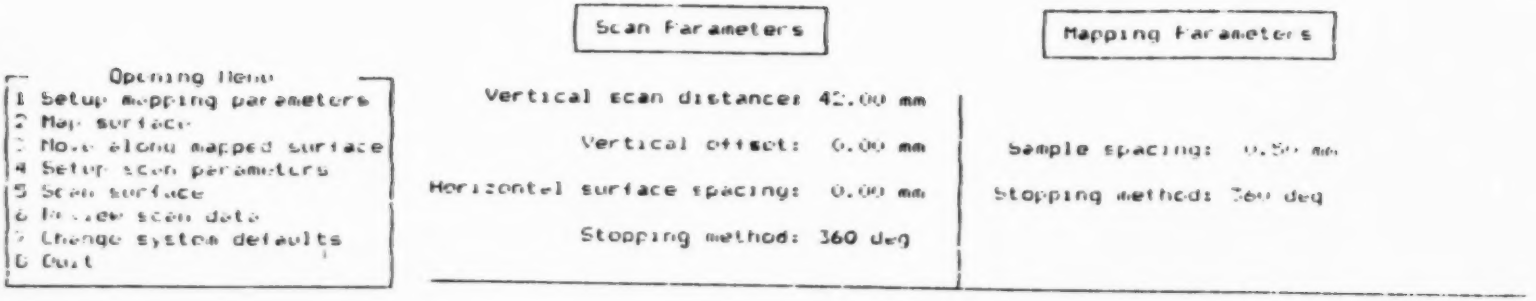
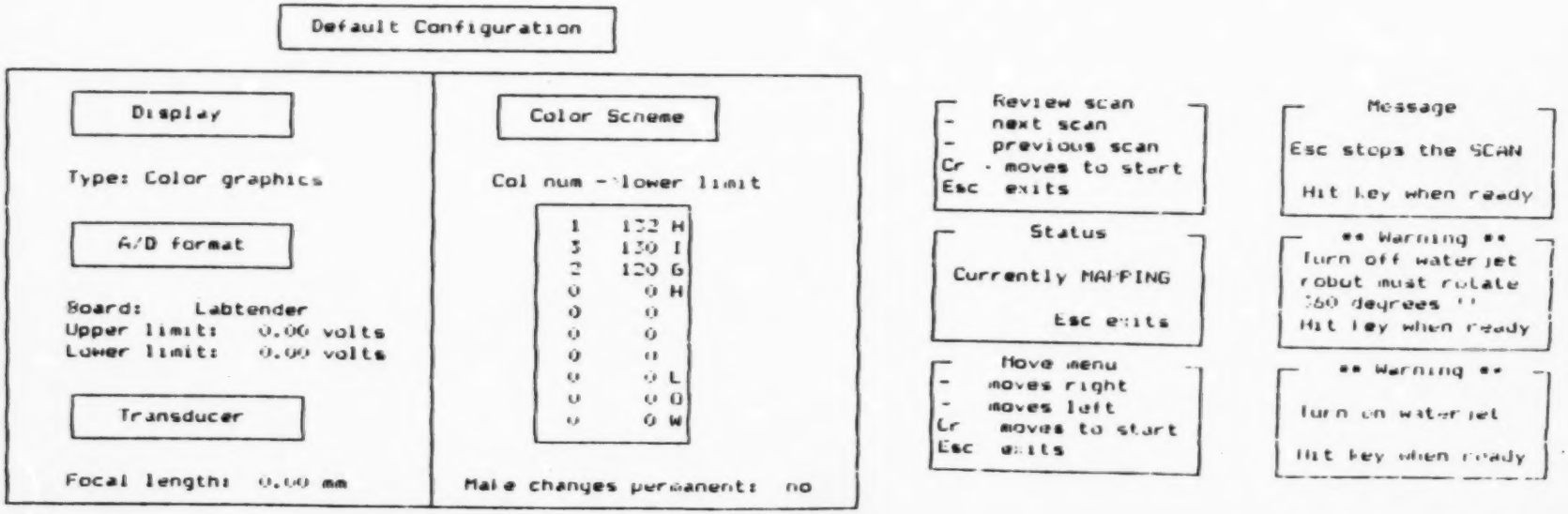


Opening Menu *Parameter Menu*



Configuration Menu *Popup Messages*

173672-RD

FIGURE 12
MENU DISPLAYS

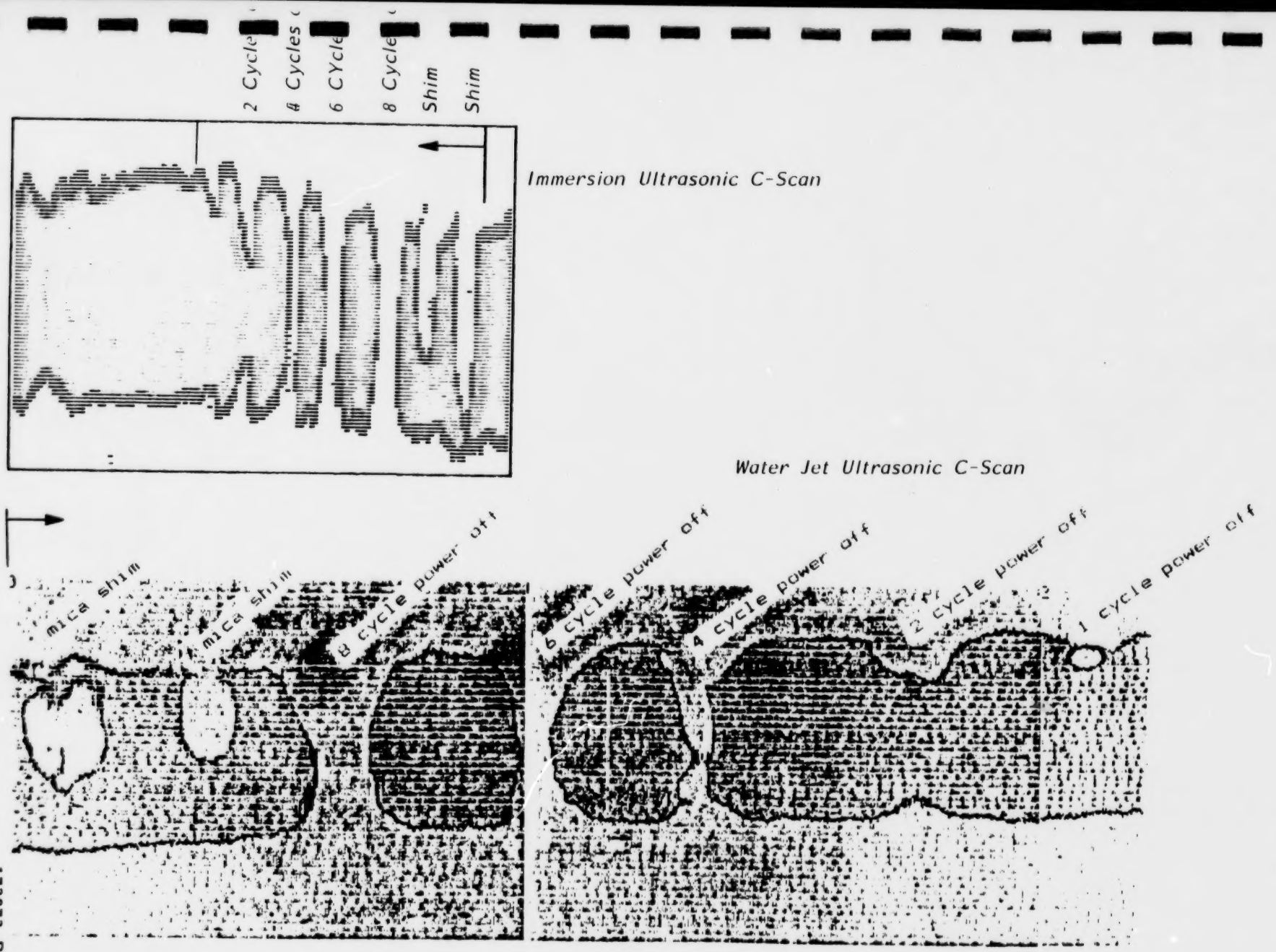


FIGURE 13

INSPECTION SYSTEM C SCAN VERSUS IMMERSION UNTRASONIC C-SPANS

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